Design and Simulation of Truck Cabin Cooling System by Vapour Absorption Refrigeration System using Engine Exhaust

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Abstract- **Air conditioning cabin of truck is the most needed research today. It is observed that significant work has not been done in the area of cabin cooling of transport truck. The temperature of cabin is high in summer and results in intolerable cabin temperatures. The available options for truck cabin cooling have been critically reviewed. The vapour absorption refrigeration cycle is found the exhaust system. The exhaust heat of truck is found to be sufficient enough for powering the proposed air conditioning system. It provides cooling effect for the driver and enhances his performance without affecting engine fuel economy. It is environment friendly as it does not use any high global warming potential (GWP) refrigerant. Our work is design and development of vapour absorption air conditioning in truck using exhaust heat which demands for future. We have designed ammonia vapour absorption refrigeration system and simulated for various parametric conditions. From this we concluded that this system found to be better alternative to the present air conditioning system in future**.

Keywords- Truck, Vapour absorption, COP, Simulink, Thermolib

I. INTRODUCTION

Truck plays a major role in the transportation of goods in road transport. They used to travel over a long distances varying region to region of different climatic conditions. The studies show that cabin temperature exceeds 55°c in summer and arid areas. It is extremely difficult for the driver to operate under such conditions. It also reduces the work efficiency of the transport drivers. So it is necessary to reduce the temperatures inside the cabin of the truck and to provide comfort to driver. The Indian government, through an amendment to the Motor vehicle act, 1988, has made it mandatory for manufacturers to fit air conditioners in the cabin in all new trucks from April 2017. The present vapour compression air conditioning system in automobile uses the engine power thus reducing fuel mileage, also the refrigerant used is not environment friendly and has high global warming potential. Considering these factors and efficiency of the system, it is very much necessary to explore new technology to satisfy the need of the society. At the same time energy conservation is also important. In case of truck large amount of heat is released. In general diesel engines have an efficiency of about 35% and thus the input energy is wasted. If the exhaust of engines are directly released to the atmosphere, it will not only waste heat but also causes the environment problems, so it is required to utilize the waste heat for useful work to increase the efficiency of the engine [1]. Considering all the above factors different alternatives have been studied and the vapour absorption system is found to be the best alternative. We have designed ammonia water vapour absorption refrigeration system and simulated the model in the MATLAB simulink using Themolib library function. The simulation is done to predict the performance of the system. The vapour absorption air conditioning will provide space cooling for the truck cabin and improves the performance and efficiency of driver without affecting fuel economy.

II. VAPOUR ABSORPTION CYCLE

The Vapour absorption refrigeration system is a heat operated system. In vapour compression cycle the work required is very large because of the compression of vapour which undergoes large changes in specific volumes. In order to achieve this in, in the vapour absorption system, the refrigerant vapour is dissolved in an inert liquid as the same pressure as the evaporator as and the solution so formed is pumped to the container at the condenser pressure. Thus, liquid which is practically incompressible and undergoes practically no changes in specific volume requires very little work for raising its pressure. After raising the pressure, refrigerant is separated from solution by heating. This vapour which is at condenser pressure goes to the condenser, expansion valve and evaporator just as in vapour compression cycle. The working fluid is usually an Ammonia water or Lithium bromide solution in water. Vapour absorption system is mainly used in the system where heat energy is available free of cost like solar energy or waste energy such as exhaust from automobiles. Salim Munther (2001) [2] in his theoretical study and exhaust heat energy is capable of producing the refrigeration effect of 1.4 tons using vapour absorption refrigeration. Kim and Park (2007) have done a dynamic simulation of vapour absorption refrigeration system for 10.5 kW loads [3]. Thus the vapour absorption system is possible in air conditioning the truck cabin.

A. Ammonia/Water Absorption System

Vapour absorption refrigeration system based on ammonia water is one of the oldest refrigeration systems. In this system ammonia is used as refrigerant and water is used as absorbent. This system can be used for both refrigeration and air conditioning applications as ammonia is used for refrigerant. They are available in very small to large refrigeration capacities in application ranging from domestic refrigerators to large cold storages. Ammonia is not compatible with materials like copper, brass; hence the entire system is fabricated out of steel. The ammonia water system is operated at pressure much higher than atmospheric. So the problem of air leakage is eliminated. This system does not suffer from the problem of crystallization encountered in water lithium bromide system.

B. Absorption Cycle

The basic operation of ammonia-water absorption cycle is as follows. The ammonia vapour leaving the evaporator is readily absorbed in the low temperature hot solution in the absorber, releasing the latent heat of condensation. The temperature of the solution tends to rise, while the absorber is cooled by circulating water, absorbing the heat of the solution and maintaining the constant temperature. Ammonia rich strong solution is pumped to the generator where heat is supplied from external source. Since the boiling point of ammonia is less than that of water, the ammonia vapour is given off from the aqua ammonia solution at high pressure, and the weak solution return to the absorber through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to high pressure liquid ammonia. This liquid ammonia is throttled by the expansion valve and then evaporates, absorbing the heat of evaporation from the surrounding or brine to be chilled. This completes the simple vapour absorption cycle.

III. LOAD CALCULATION

The cooling loads are calculated by using standard method of load calculation by standard method of load calculation .The various factors influencing heat load like solar radiation through roofs and glasses, normal heat gain through wall, infiltration, metabolic heat of person travelling can be calculated using ASHRAE hand book.

TABLE 2: COOLING LOAD

PARAMETER	VALUE
Normal heat gain through walls	1.19 kW
Normal heat gain through glasses	0.33 kW
Heat radiated from engine	0.55 kW
Metabolic heat load of driver	0.33 kW
Infiltration	0.25 kW
Solar radiation	0.08 kW
Total	2.73 kW

PARAMETER	VALUE
Cabin dimension	(2.3*1.7*1.5)m^3
Engine power	160 BHP
Cabin temperature Without cooling	45°C
Ambient temperature	40°C

The maximum heat energy from the exhaust and cooling water of 160 BHP engine is calculated and it is 50kW and 40kW respectively.

IV. DESIGN

The total heat load of truck cabin is 2.73 kW therefore cooling system of 1TR (3.5kw) should be sufficient. Based on the cooling load the absorption system is designed. The schematic diagram shows the proposed absorption air conditioning system in the truck.

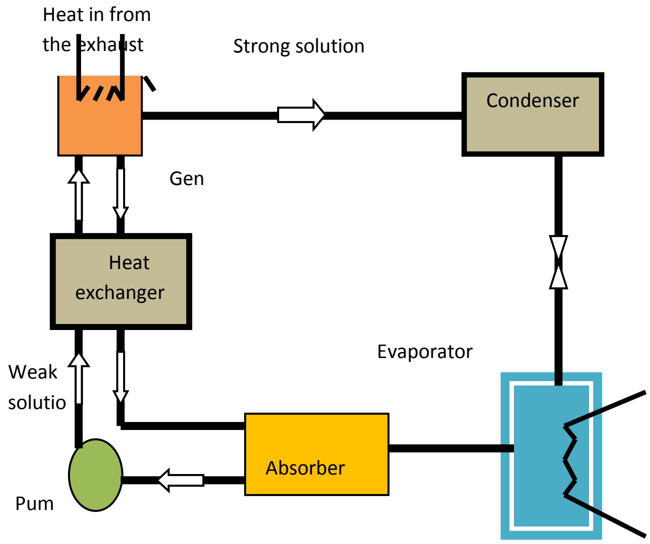

Fig-1: Schematic diagram of proposed arrangement of vapour absorption air conditioning system in truck

The exhaust heat is utilized by using the heat exchanger in the generator. It heats the solution in the generator to make it strong solution. The strong solution is condensed in the condenser where the refrigerant vapour ammonia becomes liquid. The liquid ammonia flows through the evaporator coil. The truck cabin heat is absorbed by the liquid ammonia to become vapour. Thus the temperature inside the cabin decreases to get the cooling effect. The ammonia liquid is pumped to the generator and the cycle continues. The same system can be used for heating the cabin also but the vapour from the generator bypasses the condenser and the led to the evaporator coil where it is condensed by the rejection of its latent heat to the cabin. This increases the temperature of the cabin. The heating cycle is used in winter air conditioning.

A standard set of condition for ammonia water system is referred. For a 1TR vapour absorption refrigeration system the operating conditions are obtained by applying mass & energy balance equation for each component. Considering the temperature of evaporator and condenser as the saturation temperature of ammonia used, the pressure in evaporator and condenser are decided. The generator temperature is the temperature of exhaust heat input plus the solution temperature. The generator and condenser operate at same pressure. The evaporator and absorber operate at same pressure. The pump power is obtained and found to be minimal. The absorber temperature should be the temperature of latent heat of condensation of ammonia. Counter flow heat exchangers are used for better heat recovery.

TABLE-3 DESIGN PARAMETERS OF THE SYSTEM

PARAMETER	VALUE
Refrigeration capacity	1 TR
Evaporator temperature	280 K
Generator temperature	423 K
Condenser temperature	330 K
Absorber temperature	298 K
Heat exchanger effectiveness	0.75
Power required for pump	3 kW

V. SIMULATION

We have modeled and simulated the system in MATLAB Simulink. We have installed Thermolib toolbox in the MATLAB Simulink to model and simulate the system. Thermolib toolbox has pre-programmed thermodynamic system blocks. Thermolib can be used for all types of energy related areas like power generation, process industries, heating and air-conditioning, as well as automotive and aerospace applications.

The absorption cycle is modeled in the simulink window using the available blocks in the thermolib tool box. Some of the blocks like absorber, generator is not directly available. They are modeled using the available blocks. The properties of the working fluids can be loaded in to the setup. Once the blocks are created the initial conditions obtained for each component is entered. Other standard requirements like heat transfer coefficient, pressure loss factor, retention factor are entered and then the model is simulated. The input output flow parameters are obtained in the flow display block. Using this block the output of all components is obtained. The flow display shows the properties like temperature, enthalpy, pressure and molar flow. The COP can also be obtained in the simulink window by logically integrating the outputs of the required components.

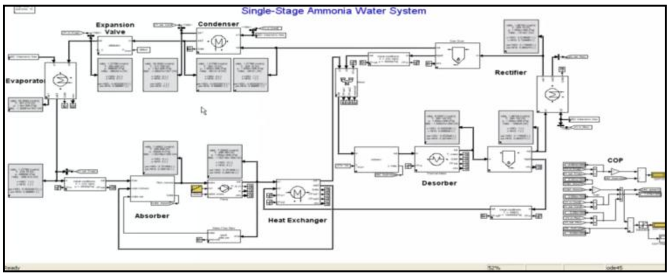

Fig-2: Vapour absorption model in simulink window

6. RESULTS AND DISCUSSIONS

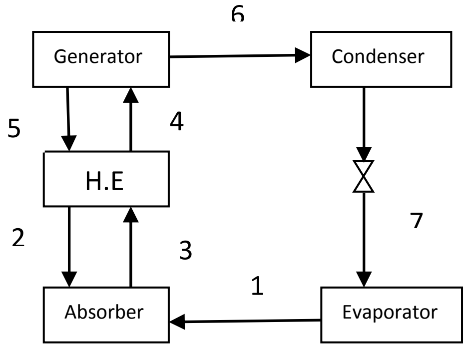

Fig-3 Block diagram of the system

Table-4: Properties Of Flow At Various States

State	Temperature (K)	Enthalpy(kj/kg)	Molar flow(mol/s)
1	280	1300	0.090
2	370	250	0.674
3	330	25	0.737
4	433	460	0.737
5	470	775	0.674
6	470	1430	0.090
7	328	280	0.090

These output values are obtained from the flow display block in the simulink. The flow display shows all the values with its corresponding units.

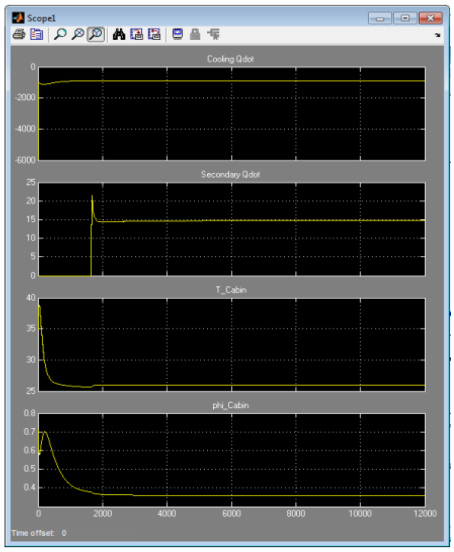

Fig-5 Output from simulink model

TABLE 5 COP FOR DIFFERENT TEMPERATURE AND CONDENSER TEMPERATURE

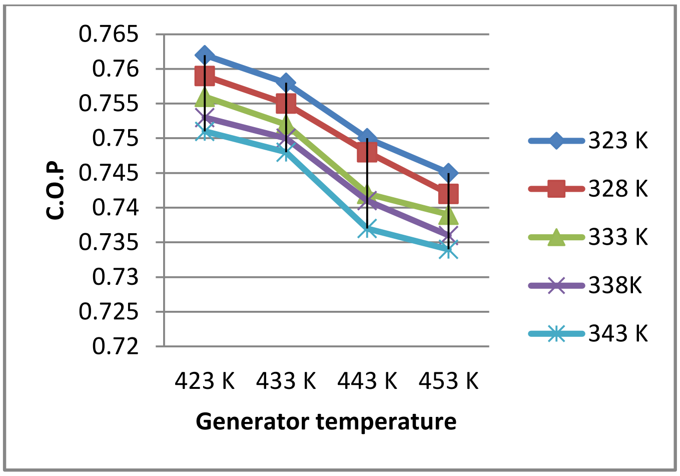

Fig-5 Generator temperature vs. C.O.P for different condenser temperature.

Generator temperature(K)	Condenser temperature (K)				
	323	328	333	338	343
423	0.762	0.759	0.756	0.753	0.751
433	0.758	0.755	0.752	0.750	0.748
443	0.750	0.748	0.742	0.741	0.737
453	0.745	0.742	0.739	0.736	0.734

The performance of the system under various operating conditions has been studied. It is plotted in graph.

- It indicates that COP varies from 0.762 to 0.734.
- It is noted that COP decreases with increase in generator temperature.
- COP also decreases with increase in condenser temperature.
- The scope output box from simulink denotes the variation of temperature inside the cabin after cooling. The temperature decreases from initial temperature of 45°C inside the cabin to the desired temperature of 25˚C.
- The desired temperature is maintained in the continuous cycle
- Heat required for 1TR with COP value of 0.7 is available from the waste heat of exhaust and cooling water. It is more than sufficient to run the absorption cycle.

7.CONCLUSION

From this paper, it has been concluded that it is possible to use the vapour absorption system in truck cabin cooling system. Though the C.O.P of the system is less, the waste heat is given as input and so the low value of C.O.P is not considered. It proves to be effective one, very economical and better alternative to the present air conditioning system.

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